VAN005

MA3T—Modeling Vehicle Market Dynamics with Consumer Segmentation

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ORNL is managed by UT-Battelle for the US Department of Energy

OAK RIDGE National Laboratory

OVERVIEW

Timeline

- Project start date: Oct 2011
- Project end date: Sep 2015

Budget (DOE share)

- FY14 funding: $350k
- FY15 funding: $350k

Barriers*

- Costs of advanced powertrains
- Behavior of manufactures and consumers
- Infrastructure
- Incentives, regulations and other policies

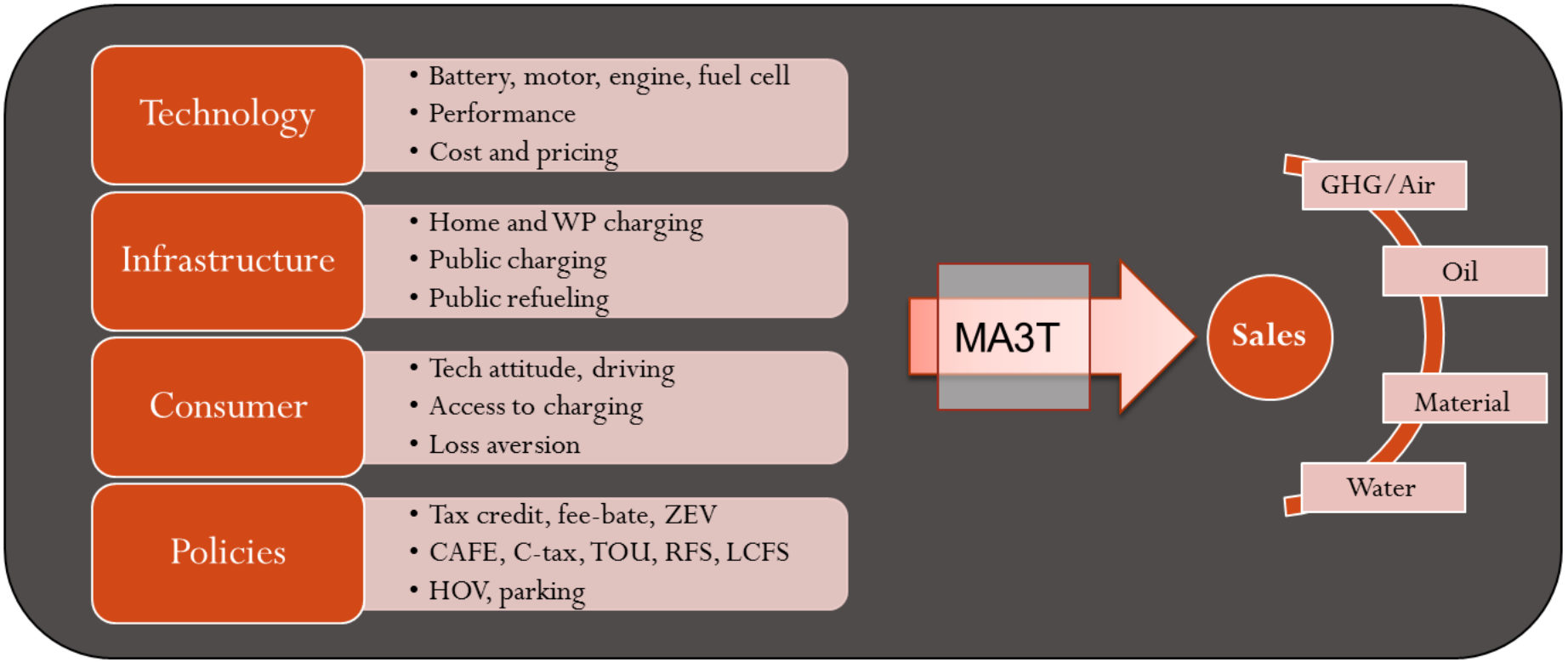
**from 2011-2015 VTP MYPP*

Partners/Collaborators

- Industry
  - Ford Motor Co., SRA Inc., Entergy Co.
- Academia
  - U. of Tennessee, UC Davis, Iowa State U., Lamar U., U. of Florida
- Government/National Lab
  - DOE, ANL, NREL, EIA
- International
  - Tsinghua University
  - IIASA

Model purpose: estimate market acceptance as a function of TICP (technology, infrastructure, behavior, policy) factors

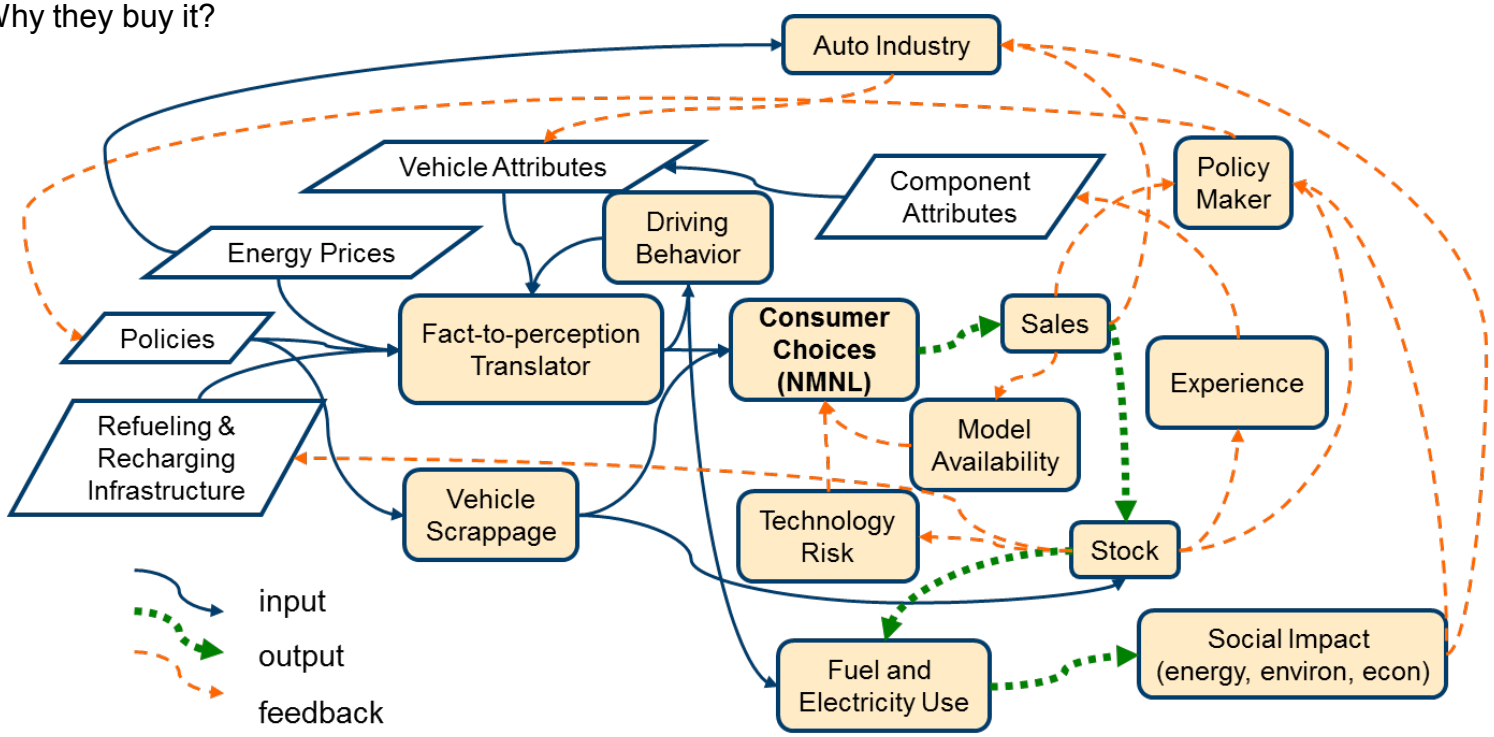
- Examples of questions addressed by MA3T
  - How will DOE R&D activities increase market adoption of clean energy technologies?



MA3T = Market Acceptance of Advanced Automotive Technologies. TICP=technology, infrastructure, behavior, policy

MA3T explores dynamics with consumer heterogeneity and technology diversity for policy/R&DD implications

- **Capture key dynamics among market players**
  - Consumers, OEMs, infrastructure/fuel suppliers, policy makers
- **Proper spatial resolution, consumer segmentation and vehicle choice structure**
  - Who will buy what, where, when and by how many?
- **Consumer-relevant attributes of technologies, infrastructure, and policy**
  - Why they buy it?



MA3T coherently models the effect of a wide range of charging options.

Lin, Z., Li, J. & Dong, J. (2014). Dynamic Wireless Charging: Potential Impact on Plug-in Electric Vehicle Adoption. *Society of Automotive Engineers Technical Papers 2014-01-1965*

Home charging energy

Work charging energy

Public charging energy

Effective electric range

$$R_e = \frac{E_h + E_w + E_p}{\max(e_e - e_w, 0^+)}$$

On-road discharge rate

On-road charging rate

On-road charging efficiency and power

$$e_w = \eta P_w O_w / V_w$$

Vehicle speed

On-road charging opportunity

$$O_w = k(A_w)$$

On-road charging availability

FY2015 milestones

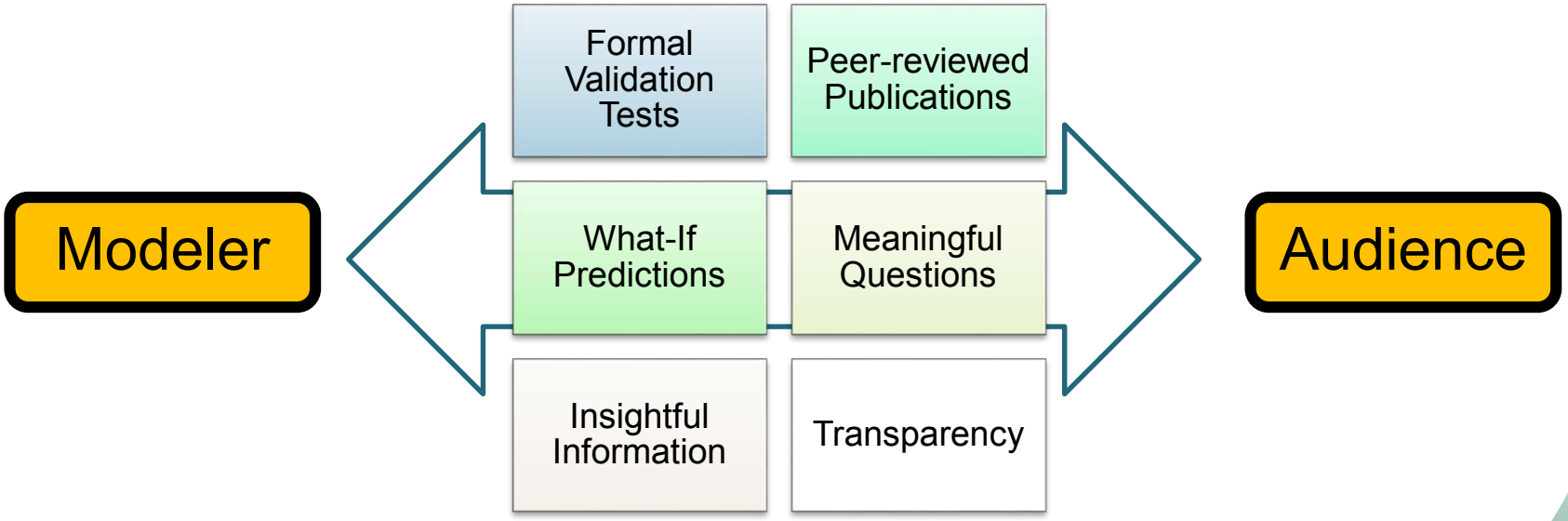
Milestone Description	Month/Year	Status
Improved representation of natural gas vehicles in MA3T	12/31/2014	Complete
Improved representation of state policies	03/31/2015	Complete
Technical documentation of MA3T	09/30/2015	On schedule
New version with energy price and vehicle data updates	09/30/2015	Complete

In FY15, six tasks to make MA3T more useful and user-friendly

- Calibration
- Validation
- Structure upgrading
- Data updating
- Application
- Publication

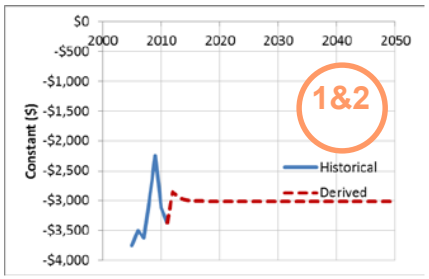
We are establishing a systematic validation process including formal tests and validity communications

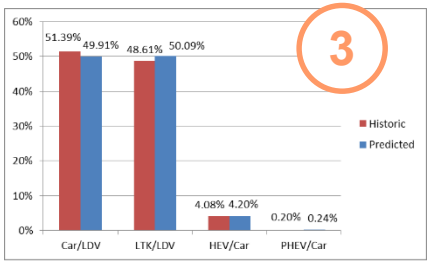
- Validation—a process of transferring confidence
- Validity goal—usefulness for the model purpose
- Usefulness measurements
- Examples

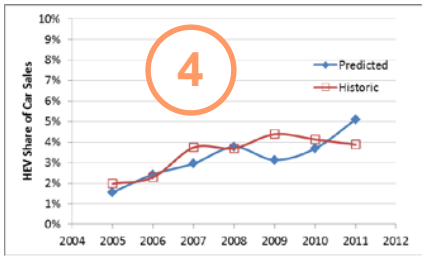


MA3T continuously "learned from history" via calibration and quasi-independent validation with available real-market data

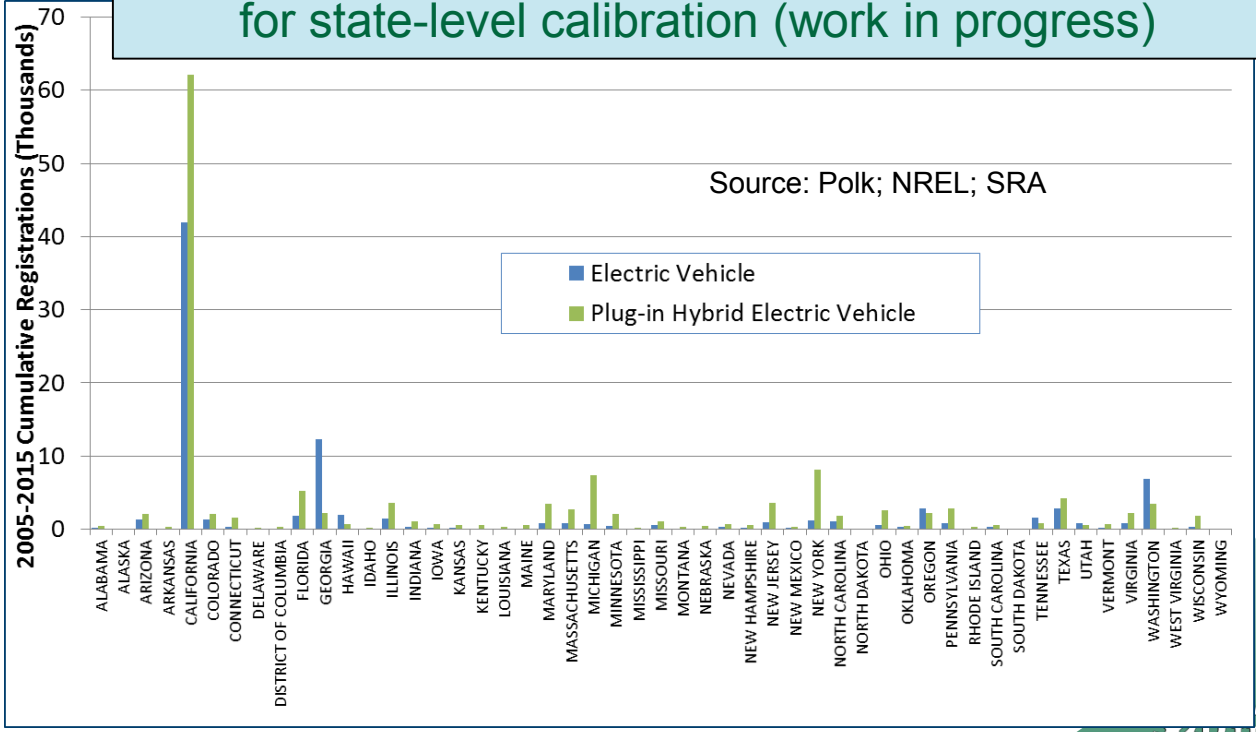
- Step 1: learning-from-history calibration of coefficients
- Step 2: asymptote-based coefficient extrapolation for future projections
- Step 3: quasi-independent validation
- Step 4: back-cast







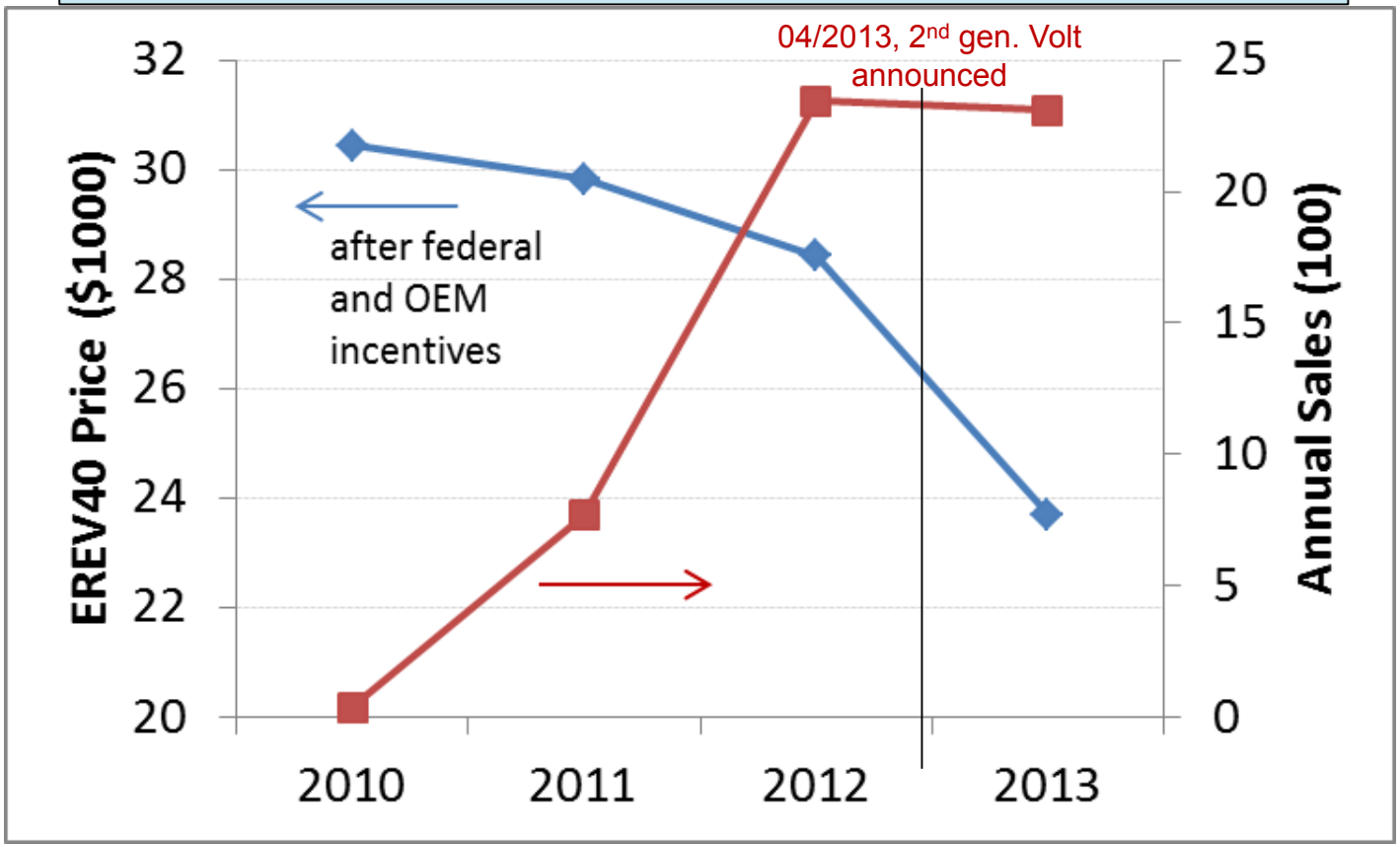
State vehicle registration data have been collected for state-level calibration (work in progress)



Behavior pattern validation tests found possible Osborne effect, important to estimate the near-term market

- We conducted several other formal validation tests, as recommended by (Barlas 1996) and (Forrester and Senge, 1980).
- No major issues found except that the behavior pattern test reveals possible Osborne effect.

Osborne effect: sales flat even with $5k OEM incentive.



In FY15, we completed major structure upgrades, interface improvements and data updates

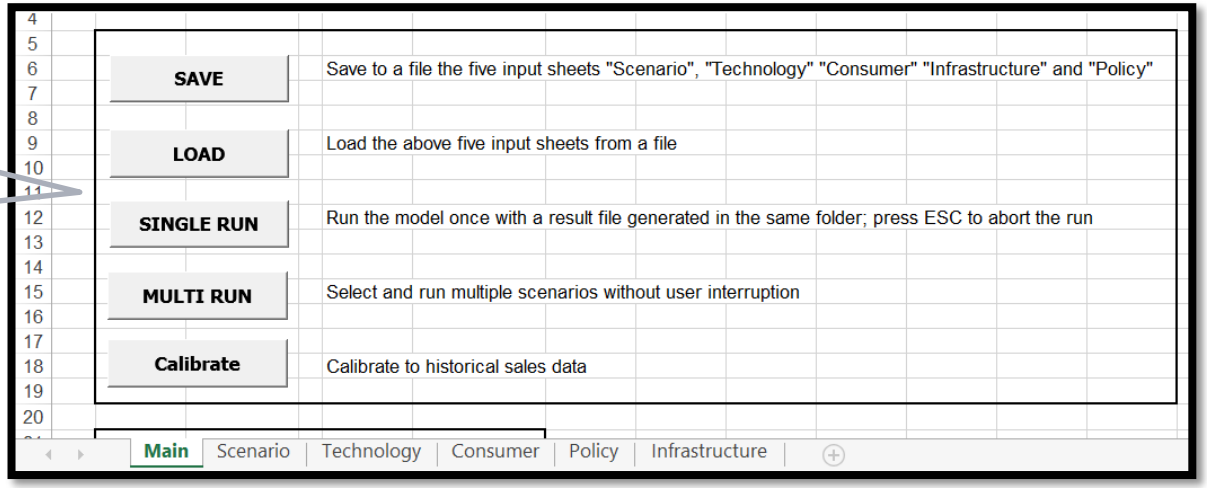
- Allow state-level analysis by disaggregating 9 census divisions to 51 states
- Improve competition fairness and policy relevance with 5 size classes, 3 variants for each powertrain choice
- State-specific mix of driver profiles and driving patterns
- BEV range uncertainty and utilization
- Transparency—all inputs/parameters moved to the user interface
- Quick navigation to input tables

In FY15, we supported several applications of MA3T

- Multi-lab (ANL, NREL, ORNL, SNL) BaSce study for VTO
- UC Davis's California energy modeling project for CEC
- IIASA's global energy modeling
- Tsinghua University's Beijing new energy vehicle market analysis for Honda
- ORNL's program benefit analysis for FCTO
- ORNL's high-octane fuel study for BETO
- UTK's study on optimal OEM pricing response to the ZEV mandate

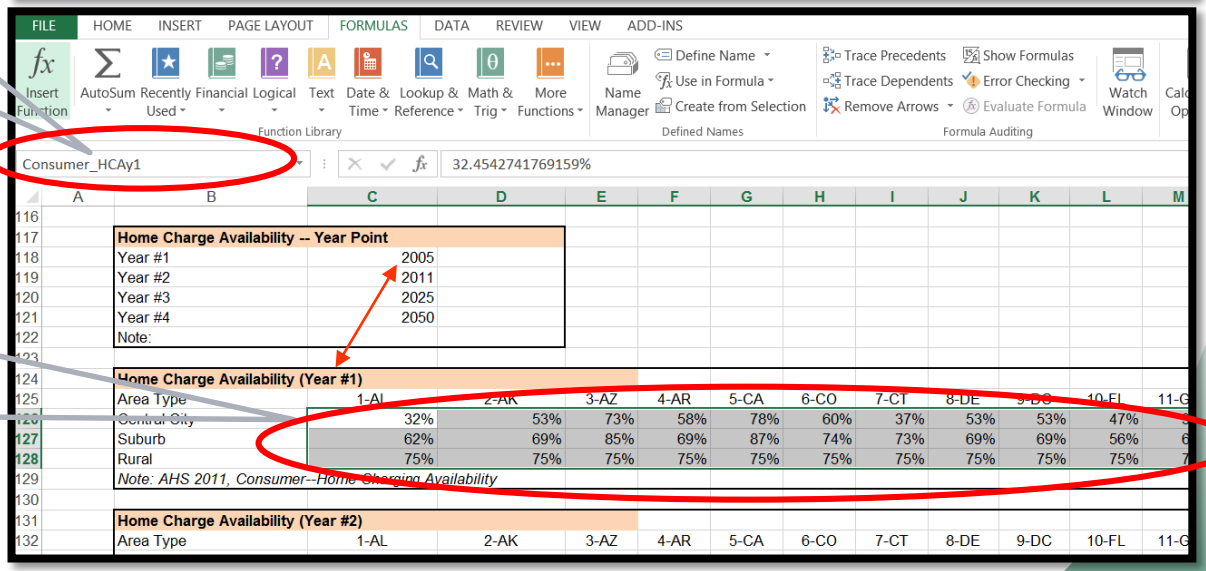
User interface was significantly improved

Model operation buttons and their function descriptions



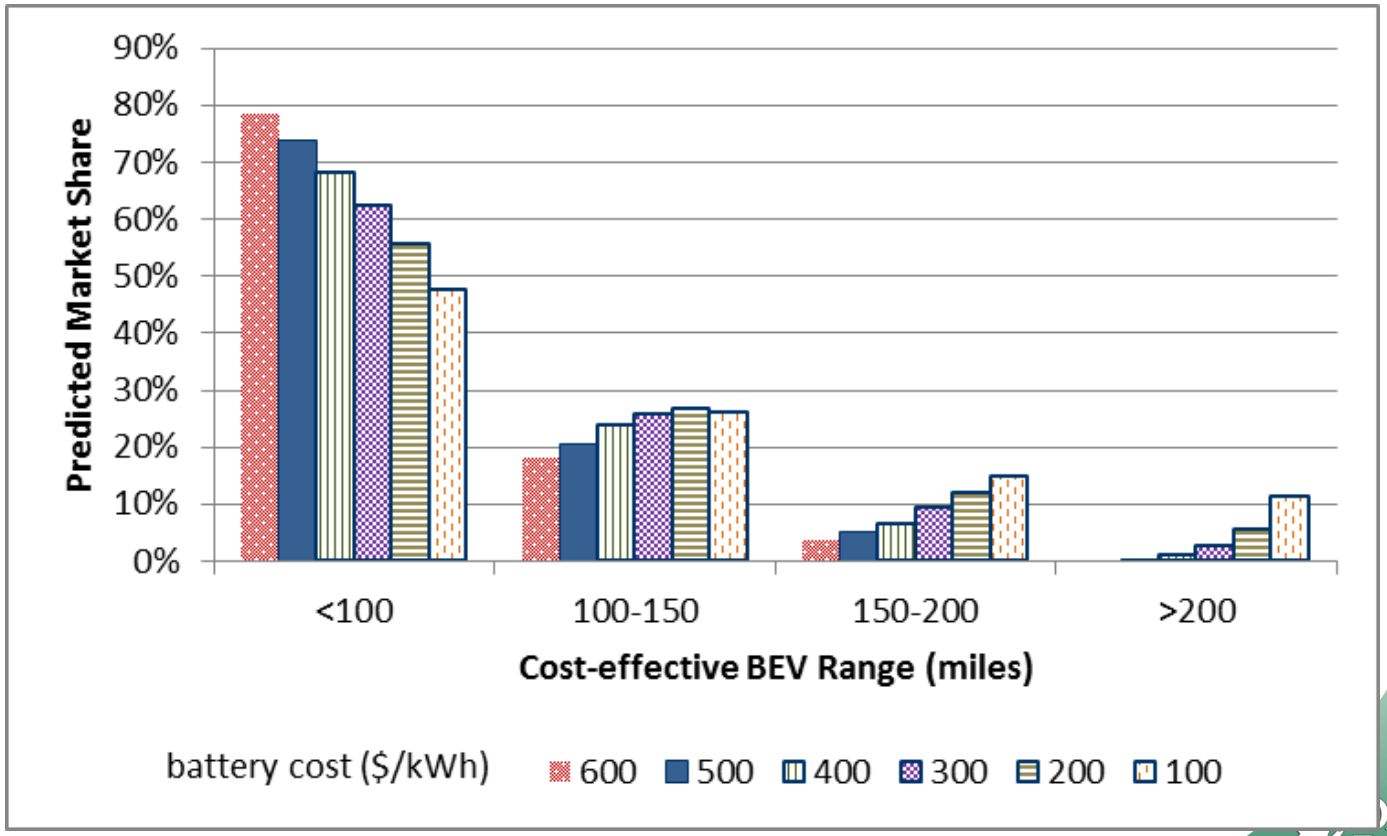
Select from the drop-down list to select the input table of interest to edit.

Excel will take you to the input table of interest, in this example, the shares of households ready for home charging in year #1 (2005) by state and residential area.



Without range uncertainty or substantial battery cost reduction, sub-100 BEVs are found to be more cost-effective for most BEV consumers.

- With battery cost decreased, long-range BEVs become more cost-effective and gain more BEV market share. Source: Lin, Z. Optimizing and Diversifying Electric Vehicle Driving Range for U.S. Drivers. *Transportation Science* 201448:4 , 635-650
- From the project, 13 peer-reviewed articles published, 5 currently under review.



Responses to past AMR reviewer comments

- The project was not reviewed on FY14 AMR.
- The FY13 AMR reviewer comments on state disaggregation and state policies have been addressed.

The success of MA3T relies on collaboration with industry, universities and government agencies

- **Ford Motor Inc.**
  - Travel patterns, electric range feasibility
- **SRA International**
  - Input data processing, state incentive, result processing, historical sales data
- **Entergy Corporation**
  - Electricity demand profile, grid impact analysis
- **Argonne National Laboratory**
  - Vehicle attribute data, application, PEV sales data, coefficient estimation, cross-examination
- **National Renewable Energy Laboratory**
  - Infrastructure roll-out scenario, infrastructure costs
  - Consumer surveys
- **Energy Information Administration**
  - Energy prices, grid carbon intensity, baseline LDV sales projection
- **University of Tennessee**
  - Model structures, coefficient estimation, consumer behavior
- **University of California, Davis**
  - Consumer behavior surveys, household vehicle usage behavior, infrastructure analysis, international energy modeling
- **Iowa State University and Lamar U.**
  - Charging behavior, range uncertainty/feasibility, Infrastructure analysis, scenario file processing, policy analysis
- **University of Florida**
  - **Workplace charging**

We need a better understanding of consumer behavior, industry behavior and value of infrastructure

- **Continued vehicle attribute and energy price updates**
- **Systematic validation**
- **Improved consumer segmentation (especially for connected and autonomous vehicles)**
- **Sensitivity analysis of state, local and OEM incentives**
- **Supply-side behavior**
  - Advanced conventional vehicles competing with PEVs
  - Business models for infrastructure
- **Insights from household vehicle usage behavior analysis**
  - Are BEVs being used differently or simply chosen by different drivers?
- **Comparison of various charging options**
  - Linking charging availability and opportunity
- **Osborne effect**
- **Documentation and outreach**
- **More publications**

SUMMARY

Relevance

- MA3T can help VTO identify TICP (technology, infrastructure, consumer and policy) opportunities to promote sustainable transportation.

Approach

- Logically link market acceptance with TICP factors with discrete choice theory, market dynamics, consumer segmentation, technology diversity

Technical accomplishments and progress

- Substantial FY15 progresses on structuring upgrades, data updates, calibration, validation, application and publication
- Highlights of structure upgrades: 51 states, NHTH 2009 driver profiles, transparent/flexible user interface
- Highlight of application highlights: IIASA integration and BaSce study
- Highlight of publication highlights: BEV range optimization on Transportation Science

Collaborations

- Strengthened and expanded
- Data support, MA3T technical support, intellectual exchange, paper co-authorship

Proposed Future Work

- Supply behavior, infrastructure value, range uncertainty, validation

ACKOWLEDGEMENTS

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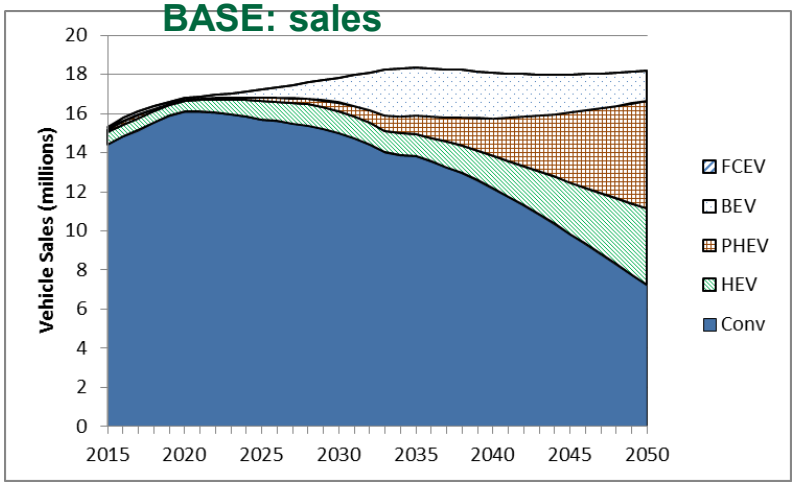
TECHNICAL BACK-UP SLIDES

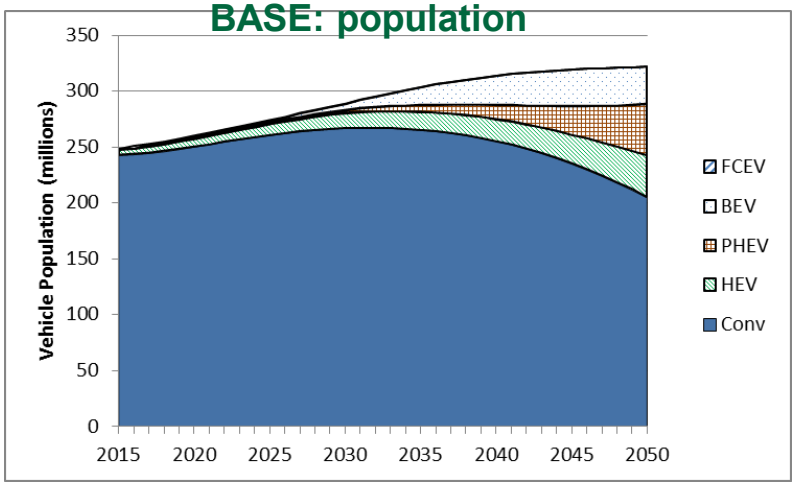
Usefulness for given purposes as measurement of model validity

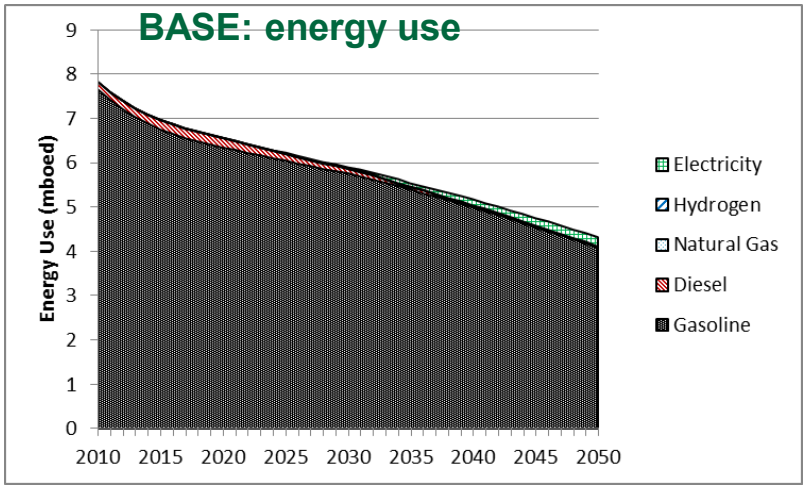
- "… it is impossible to define an absolute notion of model validity divorced from its purpose. Once validity is seen as 'usefulness with respect to some purpose', then this naturally becomes part of a larger question, which involves the 'usefulness of the purpose' itself." "Model validation is a gradual process of 'confidence building', rather than a binary 'accept/reject' division."(Barlas 1996)
- "Validation is the process of establishing confidence in the soundness and usefulness of a model." "Validation includes the communication process…to a target audience." "A model may be considered useful if it **generates insight** into the structure of real systems, **makes correct predictions**, and **stimulates meaningful questions** for future research." (Forrester and Senge, 1980)

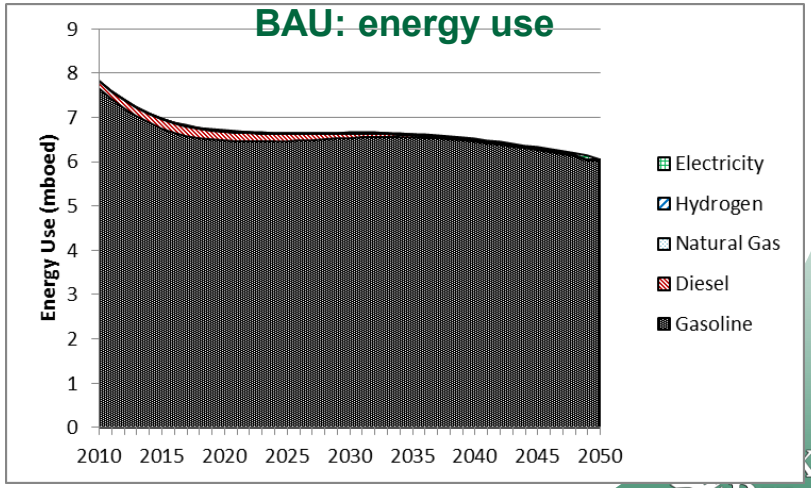
References:
1. Barlas, Yaman. 1996. Formal aspects of model validity and validation in system dynamics. System Dynamics Review Vol. 12, no. 3: 183-210
2. *Forrester, J., and P. Senge. 1980. Tests for Building Confidence in System Dynamics Models, in: System Dynamics, A.A. Legasto* Jr., ed., TIMS Studies in the Management Sciences, Vol.14, New York: North Holland 1980.

The calibrated new Baseline shows a significant BEV sales share (~15%) by 2035.

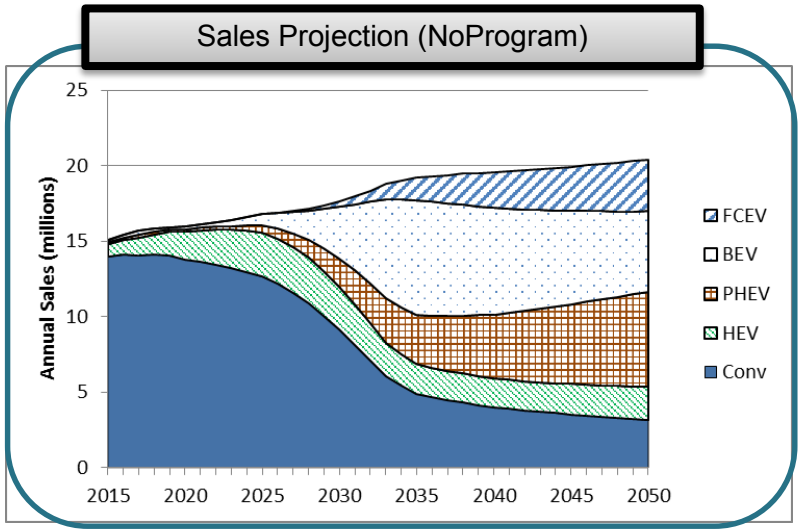


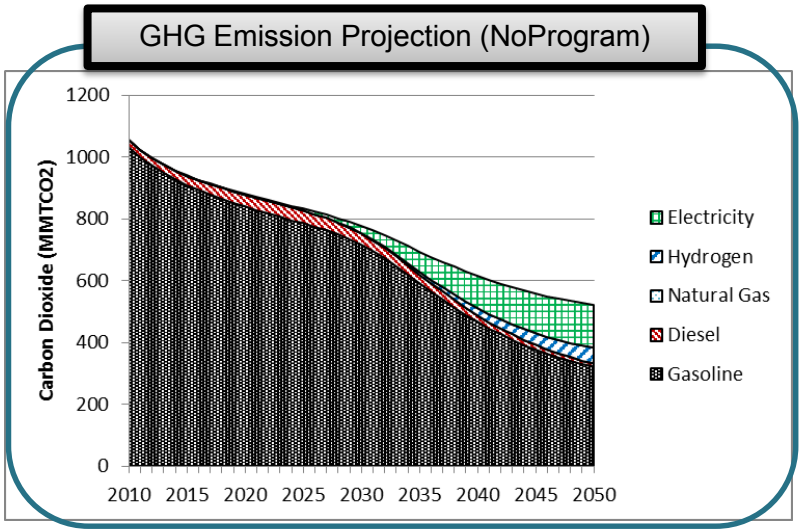


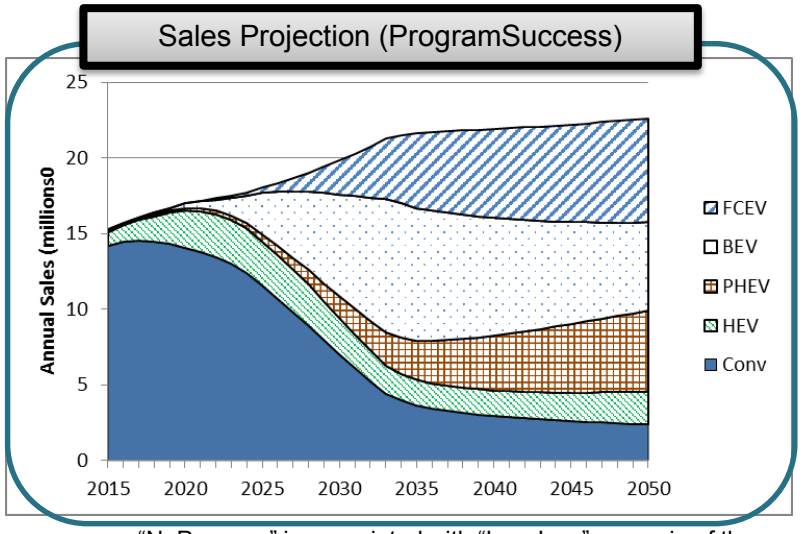


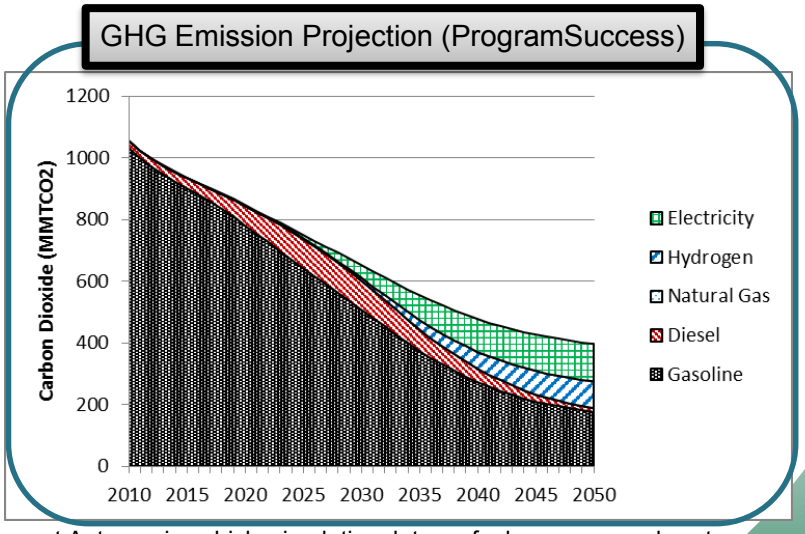


The 80/50 GHG goal requires all program targets, and renewable hydrogen and electricity.









- "NoProgram" is associated with "Low-Low" scenario of the most recent Autonomie vehicle simulation data on fuel economy and costs, representing no active pursue of DOE VTO or FCTO program activities. "ProgramSuccess" is associated with the "High-High" scenario of Autonomie, representing program targets of VTO and FCTO as if they are met on time.

13 peer-reviewed articles resulted from the MA3T project

1. Lin, Z., Li, J., & Dong, J.. (2014). Dynamic Wireless Charging: Potential Impact on Plug-in Electric Vehicle Adoption. *Society of Automotive Engineers Technical Papers 2014-01-1965 .*
2. Dong, Jing, Lin, Zhenhong, Liu, Changzheng, and Liu, Yanghe. (2014). "Assessing Grid Impact of Plug-in Electric Vehicle Charging Demand Using GPS-Based Longitudinal Travel Survey Data." *SAE Technical Papers* 2014-01-0343.
3. Dong, J., & Lin, Z.. (2014). Stochastic Modeling of Battery Electric Vehicle Driver Behavior: The Impact of Charging Infrastructure Deployment on BEV Feasibility. *Transportation Research Record (accepted)*.
4. Lin, Z. (2014). Battery Electric Vehicles: Range Optimization and Diversification for U.S. Drivers. *Transportation Science (accepted)*.
5. Wu, X., Dong, J., and Lin Z.. (2014). "Cost Analysis of Plug-in Hybrid Electric Vehicles Using GPS-Based Longitudinal Travel Data." *Energy Policy* 68: 206–17
6. Dong, J., Liu, C., & Lin, Z. (2014). Charging infrastructure planning for promoting battery electric vehicles: An activity-based approach using multiday travel data. *Transportation Research Part C: Emerging Technologies*, *38*(0), 44 – 55.
7. Greene, D. L., Lin, Z., & Dong, J. (2013). Analyzing the sensitivity of hydrogen vehicle sales to consumers' preferences. *International Journal of Hydrogen Energy*, *38*(36), 15857 – 15867.
8. Lin, Z., Dong, J., and Greene, D.L., 2013. Hydrogen Vehicles: Impacts of DOE Technical Targets on Market Acceptance and Societal Benefits. International Journal of Hydrogen Energy, Vol 38, Issue 19, Pages 7973-7985
9. Lin, Z., Dong, J., Liu, C., & Greene, D. (2012). Estimation of Energy Use by PHEVs: Validating Gamma Distribution for Random Daily Driving Distance. Transportation Research Record, 2287(1), 37-43.
10. Lin, Z. (2012). Optimizing and Diversifying the Electric Range of Plug-in Hybrid Electric Vehicles for U.S. Drivers. International Journal of Alternative Powertrains, 1(1), 108-194.
11. Dong, J., & Lin, Z. (2012). Within-day recharge of plug-in hybrid electric vehicles: Energy impact of public charging infrastructure. Transportation Research Part D: Transport and Environment, 17(5), 405-412.
12. Lin, Z., & Greene, D. L. (2011). Promoting the Market for Plug-In Hybrid and Battery Electric Vehicles: Role of Recharge Availability. Transportation Research Record, 2252(1), 49-56.
13. Lin, Z., & Greene, D. L. (2011). Assessing Energy Impact of PHEVs: Significance of Daily Distance Variation over Time and Among Drivers. Transportation Research Record, 2252(1), 99-106.

Working papers supported by the MA3T project

1. Changzheng Liu, Zhenhong Lin. “Quantifying the Uncertainty of Plug-in Electric Vehicle Market Penetration”. Manuscript submitted.
2. Xing Wu, Md.Aviquzzaman Avi, Zhenhong Lin. “Analysis of Plug-In Hybrid Electric Vehicles’ Utility Factors Using GPS-based Longitudinal Travel Data”. Manuscript submitted.
3. Jing Dong, Xing Wu, Changzheng Liu and Zhenhong Lin. “A Cumulative Prospect Theory Approach to Assess the Value of Reliable Range Estimation for Battery Electric Vehicles”. Manuscript submitted.
4. Eleftheria Kontou, Yafeng Yin, Zhenhong Lin. “Socially Optimal All-Electric Driving Range of Plug-in Hybrid Electric Vehicles”. Manuscript submitted.
5. Sangsoo Park, Changzheng Liu, Zhenhong Lin. “Vehicle Consumer Preference Heterogeneity: Random Coefficient Logit Approach with 2000 – 2013 Sales Data”. Manuscript submitted.